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30/20 GHZ FLIGHT EXPERIMENT SYSTEM
PHASE II FINAL REPORT

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S. Reisenfeld

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16. Abstract

The development plan for the 30/20 GHz flight experiment system is based on many previous experiences with communication satellites produced by Hughes Aircraft Company. A master program schedule with detailed development plans for each subsystem is planned with careful attention given to new technology items to ensure a minimal risk. The work breakdown structure (WBS) shows the organization of the program management with detailed task definitions. The ROM costs (1981 $M) based on the development plan are also given.

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1. SYSTEM SUMMARY

The communications concept is illustrated by the block diagram of the satellite payload (Figure 1-1). It consists of trunking service (TS) and customer premise service (CPS) experiments. The trunking system serves four spot beams which are interconnected in a satellite switched time division multiple access (SS TDMA) mode by an IF switch matrix. The CPS system covers two large areas in the eastern half of the United States with a pair of scanning beams. The individual spots which comprise these CPS areas are interconnected through a baseband processor (BBP) on board the satellite. Both trunk and CPS systems use an antenna with a 10 foot main reflector. The downlink data rate of 256 Mbps (for both trunk and CPS) are supported by 40 watt TWTAs being developed for NASA by Hughes Electron Dynamics Division. Since the trunk and CPS services are not simultaneous, the trunk TWTAs are also used for the CPS. The CPS total uplink data rate is broken in 32 Mbps uplink channels so that low cost earth stations can be employed.

The NASA 30/20 GHz flight experiment has a 2 year duration, however, the satellite is to be designed for a 4 year lifetime so that additional use of the satellite can be made by industry if there is a need. The spacecraft propulsion system must have fuel for 4 years of stationkeeping in both inclination, longitude, and spacecraft attitude.

It is a NASA requirement that the communication payload be installed on an existing spacecraft bus. A 4 year lifetime is required. The bus employed by Hughes is the LEASAT spacecraft. Figure 1-2 shows the 30/20 GHz flight experiment installed on the LEASAT bus. The antenna employs a Cassegrain configuration. The planar surface is a frequency selective screen which separates the transmit and receive signals. The trunk feeds are part of the scanning beam feed arrays which are shown. The 20 GHz beacon antenna is also visible. The beacon signal is available on propagation measurements anywhere in the contiguous United States (CONUS). It also carries the telemetry and ranging data.

The LEASAT spacecraft configuration is shown in Figure 1-3. It is the first communication satellite designed to be launched only by the Space Shuttle and to take full advantage of the Shuttle's considerable launch cost savings. In its launch configuration, LEASAT is 422 cm in diameter and 430 cm in height. The spacecraft is a dual spin configuration, with a rate of

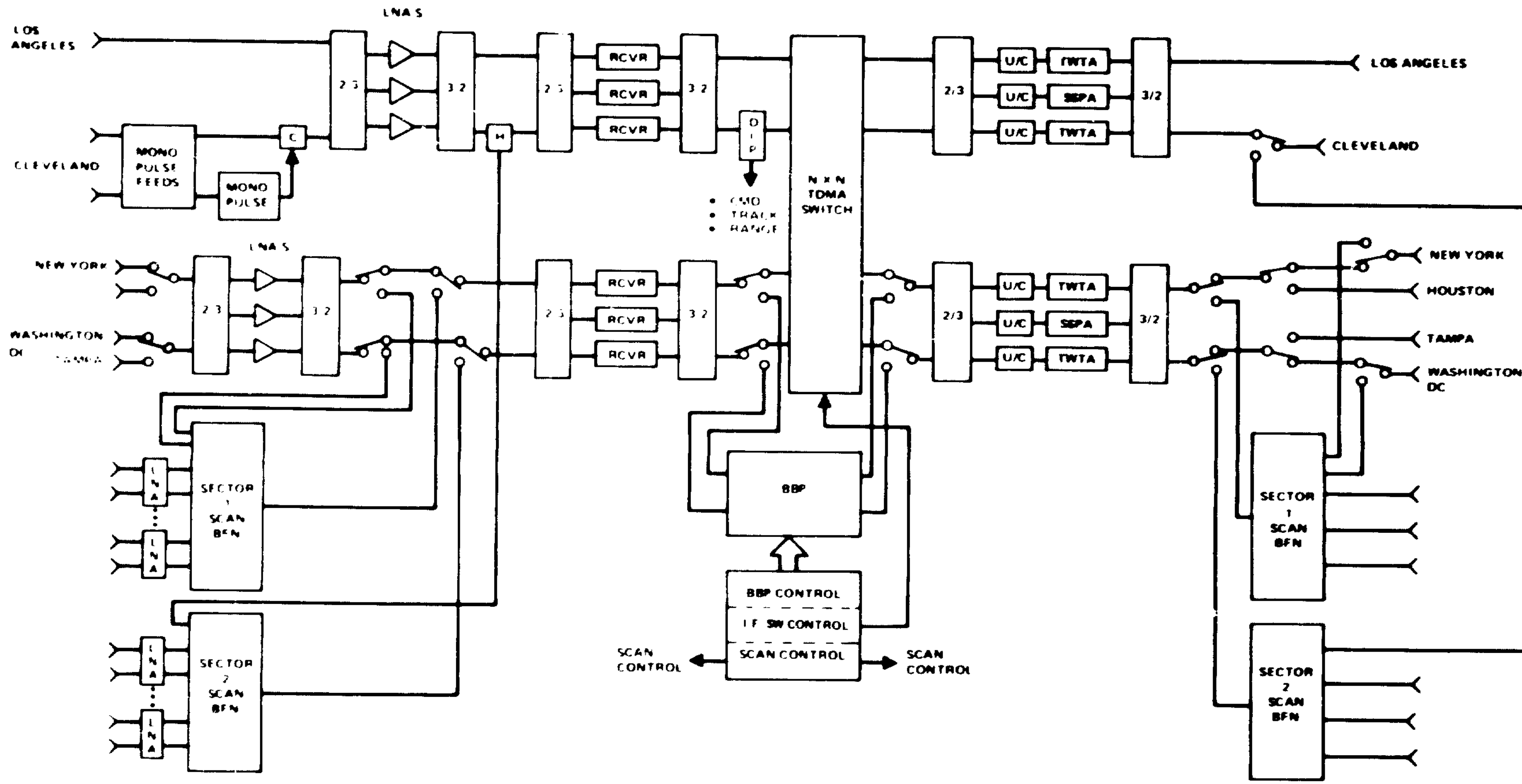

FIGURE 1-1. SPACECRAFT FUNCTIONAL BLOCK DIAGRAM

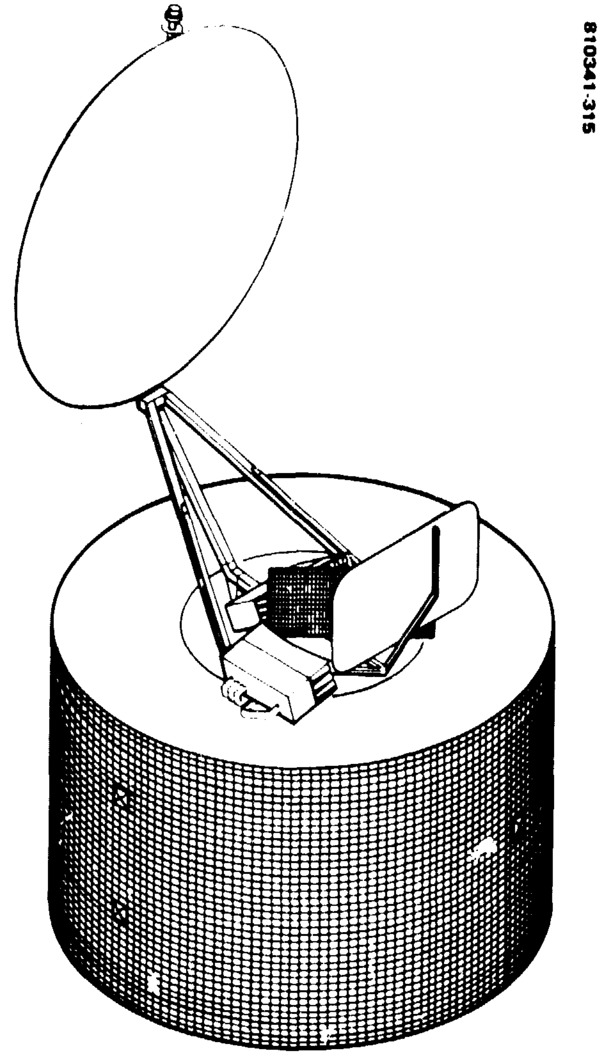

FIGURE 1-2. SPACECRAFT ISOMETRIC

30 rpm on station. The spinning section contains the propulsion, attitude control, and power subsystems. The despun section contains the telemetry, command, and communication subsystems and the spacecraft's earth pointing antennas. The antennas and the equipment on the despun platform are replaced by the 30/20 GHz payload. The spinning section is virtually unchanged.

The LEASAT propulsion system incorporates the perigee and apogee stages needed to lift the spacecraft from low Shuttle orbit into synchronous orbit. A liquid propellant system will be used for perigee augmentation and the complete apogee impulse. Four years of on-orbit station keeping and attitude control will be provided by a standard monopropellant hydrazine system.

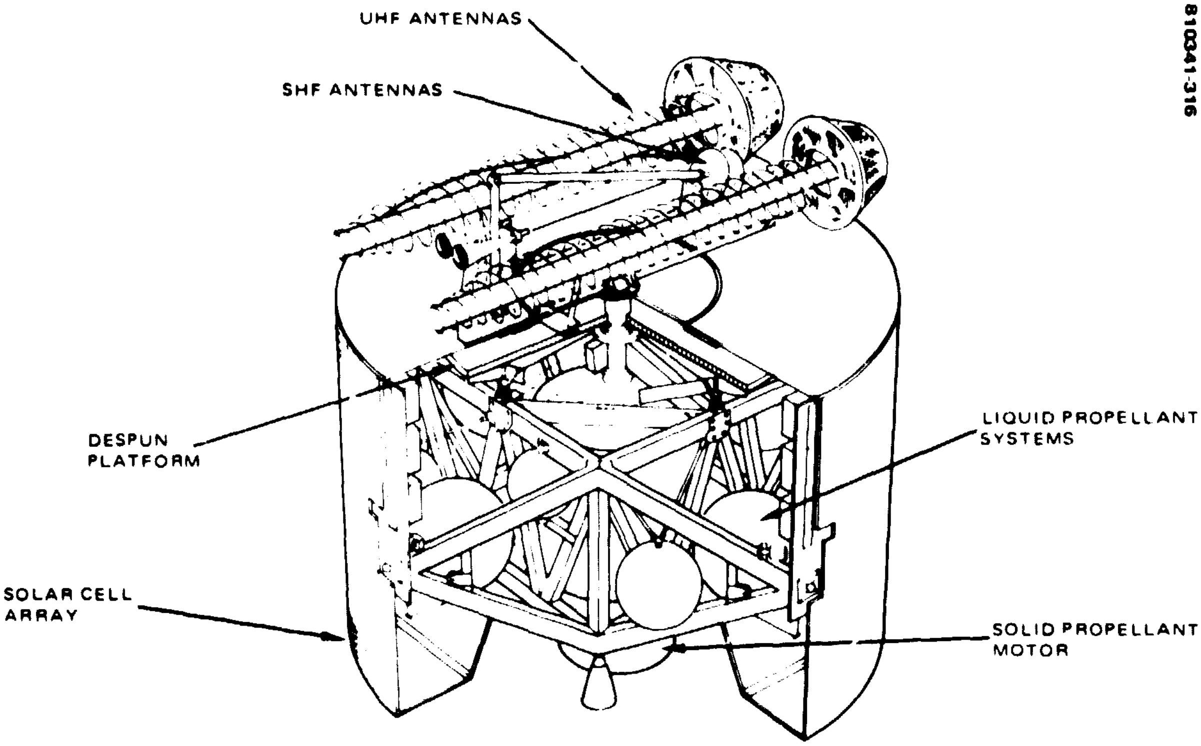

FIGURE 1-3. LEASAT SPACECRAFT STOWED CONFIGURATION

TABLE 1-1. SPACECRAFT WEIGHT SUMMARY

Item	Payload Weight, lb	
Payload		465
Antenna	189	
Microwave	123	
Digital	111	
Margin (10%)	42	
Bus		2,285
TT&C	123	
Controls	75	
Power	541	
Propulsion	323	
Structure	1,100	
Margin (rotor)	114	
Spacecraft (dry)		2,750
Propellant (BOL)		345
RCS (4^{+} yr)	324	
LAM residual	21	
Spacecraft (BOL)		3,095
Transfer orbit expendables		12,191
Shuttle deployment		15,286
Cradle and ASE		1,785
Shuttle payload		17,071

The 30/20 GHz flight experiment vehicle will weigh 17,071 pounds in the Shuttle bay and 3,095 pounds when it reaches synchronous orbit. Its weight at the end of 4 years will be 2,750 pounds. A weight summary is given in Table 1-1. The total spacecraft weight margin provided by excess propulsion capability is 156 pounds. A 10 percent payload weight margin of 42 pounds was allocated to the payload leaving 114 pounds as rotor weight margin. The ultimate limit in payload weight is the stability requirement that the spin to transverse inertia (I_s/I_t) ratio be greater than 1.05. As much as half of the 114 pound rotor margin could be reallocated to the payload if the remainder of the rotor margin were positioned near the perimeter of the rotor. The actual fraction of the 114 pounds which is available for the payload depends on whether the payload weight growth was above the despun platform (e.g., antenna) or in the despun platform which is near the center of gravity. If the first of two options which were studied at NASA's direction were implemented, the payload weight would be reduced by 49 pounds by eliminating one of the scanning beams and reducing the BBP throughput. The additional margin provided by option 1 does not appear necessary. The second option, which added an FDMA capability to the payload, added 16 pounds to the payload. Adoption of option 2 would appear to leave adequate margin. Also, option 2 could be removed if necessary without any significant effect on the remainder of the payload.

Table 1-2 is a power summary of the 30/20 GHz spacecraft. The major portion of the trunking service payload power is for the four 40 watt TWTAs. In the CPS mode, only two of the TWTAs are used but the BBP, which is used primarily for the CPS mode, replaces these TWTAs as a power user. The effect in power demand of the two options is insignificant compared to the very large power margin.

TABLE 1-2. POWER SUMMARY (WATTS)

Item	Baseline	
	TS	CPS
Payload		
Antenna	1.8	9.8
Microwave	515.6	285.6
Digital	41	223.2
Bus	228	228
TT&C (48)		
Controls (37)		
Power (92)		
Thermal (51)		
Spacecraft	786.4	746.6
Capability (4 yr)	1,090	1,090
Margin	303.6	343.3

The 30/20 GHz flight experiment spacecraft will be carried in the Space Shuttle as shown in Figures 1-4 and 1-5. It will be held in the Shuttle bay by a reusable cradle, which attached to the mainframe of the Shuttle at five points. While the Shuttle is orbiting at an altitude of 160 n.mi., the spacecraft will be ejected by two springs which supply a separation of 160 n.mi., the spacecraft will be ejected by two springs which supply a separation velocity of 40 cm/sec and a rotational speed of 1.8 rpm. Spinup rockets will increase the satellite's rate to 30 rpm approximately 300 seconds after release. The solid propellant perigee motor will be fired 45 minutes after release. The empty motor case and its supporting structure will then be dropped. The liquid propellant motors will supply the additional velocity needed to put the spacecraft in elliptic transfer orbit. On reaching synchronous orbit, the communications antenna will be deployed and operational service will begin.

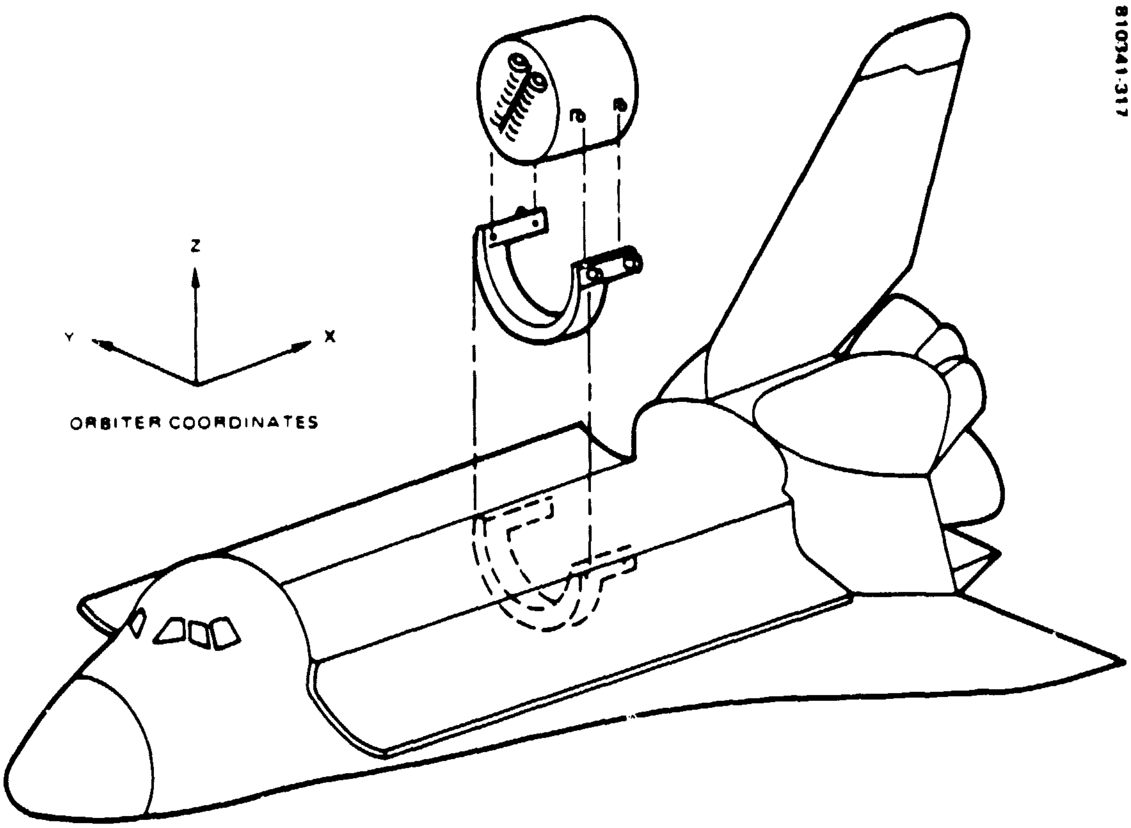

FIGURE 1-4. LAUNCH CONFIGURATION

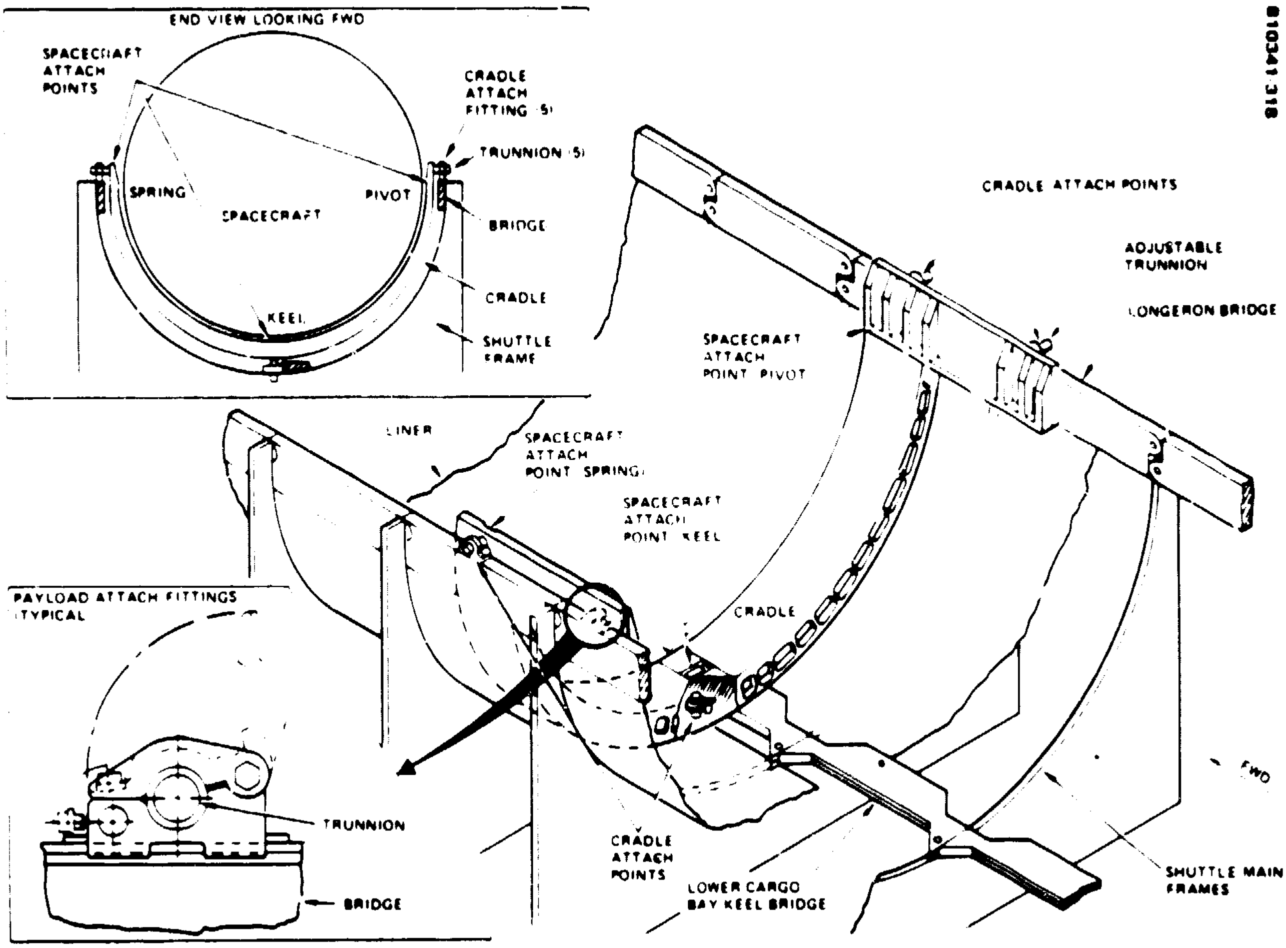

FIGURE 1-5. TYPICAL CRADLE SHUTTLE BAY INSTALLATION

A summary estimate of the reliability of the space segment is given in Table 1-3. The reliability of the launch and orbit insertion is included in the estimates. The estimate uses an existing reliability estimate for the LEASAT bus and the number and type of parts used in the payload. The assumptions and model used are described in 4.3, Space Vehicle Reliability.

The reliability shown is quite adequate to meet mission objectives, particularly since the partial failures of case 4 will not seriously interfere with these objectives. The scanning beams each have a total of 16 spots in the uplink and 10 spots in the downlink so the loss of one spot from each of the two areas can be tolerated. The reason for the lower reliability of the CPS relative to the trunking service is the complexity of the beam forming networks of the scanning beams.

The terrestrial segment of the 30/20 GHz flight experiment consists of trunk terminals, CPS terminals, and a master control terminal (MCT). The trunk terminals have 5 meter antennas and employ site diversity to improve propagation reliability. The CPS stations are of two types: 1) small stations which transmit at a 32 Mbps burst rate and use a 3 meter antenna, and 2) large stations which transmit at 128 Mbps and use 5 meter antennas. All terminals receive at 256 Mbps. The MCT consists of a trunk terminal and a central control station which controls both the communication network and the spacecraft operation. NASA will procure the MCT and a small CPS terminal; experimenters will procure other terminals.

TABLE 1-3. SPACE SEGMENT RELIABILITY

Item	2 years	4 years
1) Complete communication capability	0.80	0.62
2) Complete trunk capability	0.94	0.81
3) Complete CPS capability	0.81	0.65
4) Loss of no more than 1 of 4 trunk beams and no more than 1 spot from each scanning beam	0.92	0.79

2. 30/20 GHz SYSTEM DEVELOPMENT PLAN

The 30/20 GHz system development plan is based heavily on experience with previous communication satellite systems produced by the Hughes Aircraft Company. Since the spacecraft bus is almost identical to that of the current LEASAT bus presently under development, its production and subsequent system integration and test will have been well established. A bonus derived from the use of the LEASAT bus is the elimination of an intermediate upper stage and the attendant management, development, interface, and cost tasks. The LEASAT has an integrated built-in perigee boost capability that not only simplifies programmatic aspects, but optimizes launch cost-effectiveness and enhances shuttle sharing flexibility.

The flight system payload is based on technology that is presently in its embryonic stage. This implies that careful attention be given to these new technology items to ensure a minimum risk is imparted to the final experimental 30/20 GHz flight system. Towards this objective, the payload subsystem: antenna, digital, and microwave, although utilizing all possible results from the technology efforts currently in progress, will be developed beginning with breadboards, brassboards, and engineering models. In the case of the digital baseband processor, these additional tasks plus the need for a significant preprogram LSI development effort will result in a tight critical program schedule.

The terrestrial segment of the system presents no critical development or schedule problems because of the lengthy time period determined by the overall program schedule. Such key items as 30/20 GHz TWTAs and receivers, and high data rate modems can be engineered and developed within the allotted schedule. The complex total system architecture that primarily impacts the ground system software will be given special emphasis early in the program to ensure that all system elements interact and perform properly and in a cost-effective manner.

The guidelines that apply to the 30/20 GHz program are listed in Table 2-1.

The development plan is based on Hughes making all components and subsystems other than the earth station antennas. This was done to understand the problems in detail and set the base for make or buy decisions. All communication components will be subjected to make or buy decisions prior to the execution phase.

TABLE 2-1. 30/20 GHz PROGRAM GUIDELINES

- Contact go-ahead, 1 August 1983
- Launch date, 1 October 1987
- Single flight system plus spare subsystems
- One trunking diversity terminal, Cleveland
- Master control station (MCS), Cleveland
- One customer premise service terminal, mobile
- 2 year mission/experiment operations support
- LEASAT bus
- Turnkey experimental system
- 1983 technology

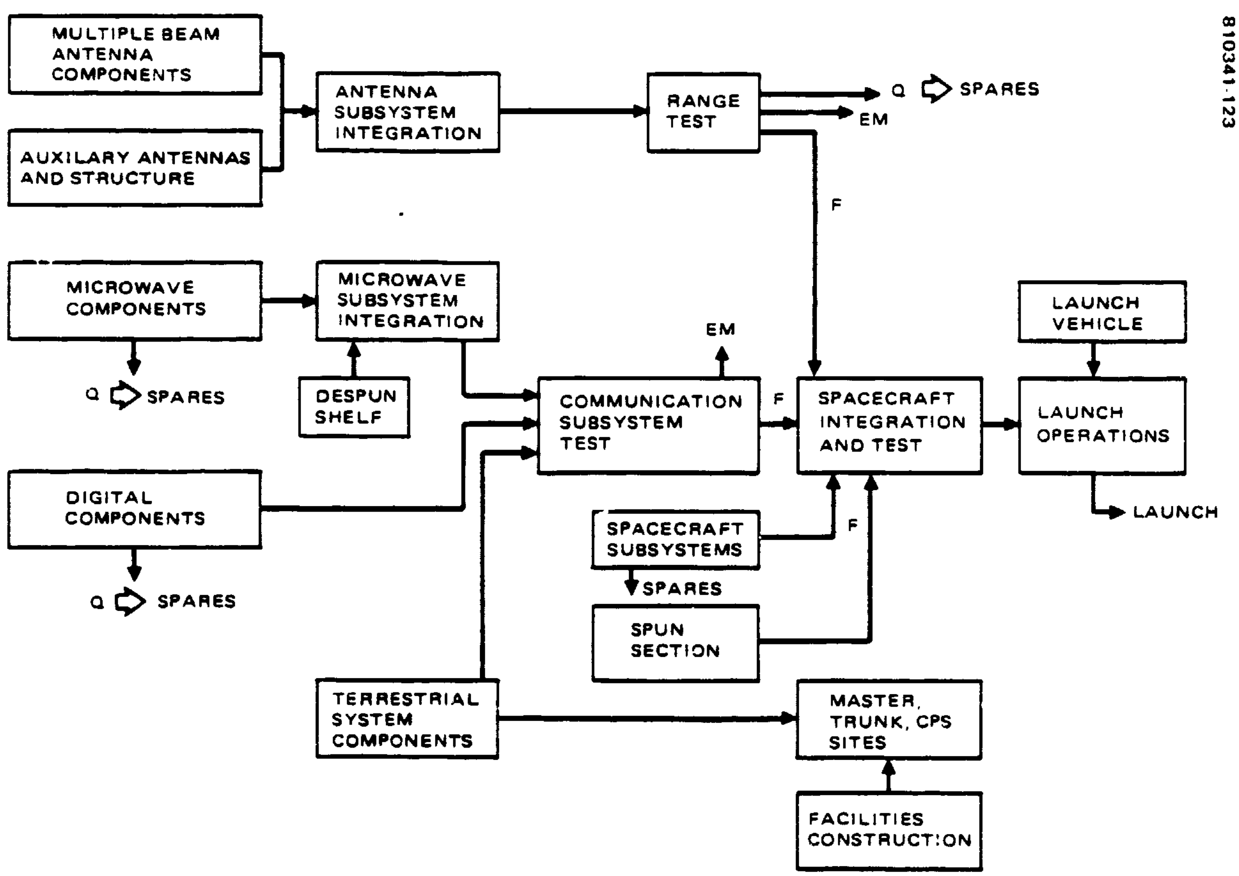

FIGURE 2-1. 30/20 GHZ PROGRAM FLOW

2.1 PROGRAM FLOW

The elements of the 30/20 GHz system along with their integration, test, and final verification are illustrated on the program flow chart (see Figure 2-1). The multibeam antenna components, auxiliary antennas, and structure are integrated and range tested. This is done for the engineering model, qualification model, and flight model. The qualification model is refurbished and becomes the optional spare. After completing range tests, the antenna subsystem is delivered to the spacecraft system integration and test area.

The microwave components are completed and integrated with the spacecraft despun shelf to produce the microwave subsystem. An engineering model, flight model, and optional spare subsystem will be developed. The microwave qualification units will be used as spares for the flight and optional programs.

Prior to delivery of the microwave subsystem to spacecraft system integration and test, it is integrated with the digital components for an all-up communications subsystem test. This key test also will include elements of the terrestrial system and be performed in an end-to-end configuration to ensure that all components of this complex subsystem perform together properly. The qualification model digital components will be used as spares for the flight and optional spare systems.

The remaining spacecraft bus subsystems: telemetry and command, controls, power, propulsion, and spinning structure and harness, are delivered along with the communications/antenna subsystems for all-up integration and test. The bus will include a flight and optional spare system plus a set of spare units. Spacecraft integration and testing will consist of a complete buildup of the spacecraft, and ambient and environmental tests. Emphasis during this phase is placed on end-to-end testing over the complete range of environmental conditions.

The final phase of the program flow consists of prelaunch checkout, integration with the Shuttle, and launch. During this final period, assembly and checkout of the terrestrial system will proceed in parallel and a final total systems readiness test will be performed to verify flight and ground segment integrity.

2.2 MASTER PROGRAM SCHEDULE

The 30/20 GHz Program Schedule, Figure 2-2, is bounded by a contract go-ahead date of August 1983 and a launch date of October 1987, or 50 months. The 15 months prior to launch are allocated for system integration, test, and launch operations, leaving 35 months for design, fabrication, and test of all flight subsystems. Since the bus is a LEASAT with minimum modification, it presents no schedule problems. The despun payload shelf will need modifications to relocate units, but there is ample time within the schedule.

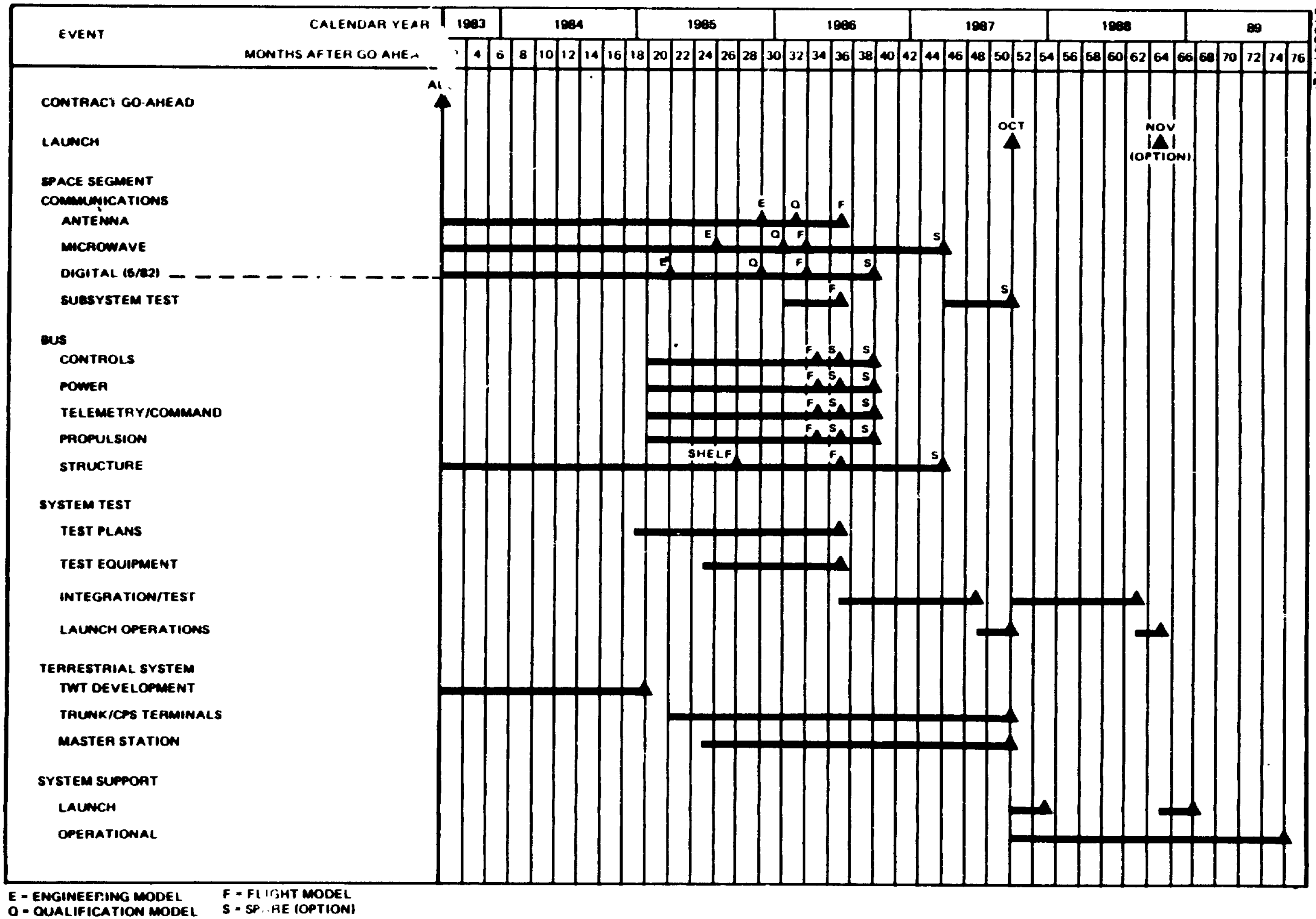

FIGURE 2-2. 30/20 GHZ PROGRAM SCHEDULE

The antenna and microwave subsystems can be developed within the schedule, but not without some concern and therefore risk. The antenna schedule could be slipped a few months because it is not needed immediately for system integration and test. The microwave (and digital) subsystem is needed for the overall communication subsystem test that already has been compressed, and therefore its schedule is firm.

The digital subsystem is known to present schedule risks. To meet the present schedule a preprogram effort must begin at least 15 months before formal program go-ahead, May 1982. This period is necessary to develop selected LSI components and define the baseband processor specifications. Even with an advanced effort, the technology and attendant problems result in the digital subsystem schedule being the high risk phase of the overall 30/20 GHz program schedule.

The terrestrial system schedule is comfortable for development of the terminals and master control station including a special phase needed to produce the new 30 GHz TWTs.

Following delivery of the flight system items, the spare subsystems for an optional system are produced. If the option is exercised by October 1987, the new system can be integrated and tested and be ready for a November 1988 launch.

Also shown on the schedule are 90 days of mission operations support for each flight, and 24 months of support for mission, communications and experiment operations following the October 1987 launch.

2.3 DETAILED DEVELOPMENT PLANS

2.3.1 Antenna Subsystem

The design and analysis of the reflector, subreflector, feeds, frequency selective surface and support structures and the assembly layout on the bus will start at program go-ahead and run continuously for at least 18 months (Figure 2-3). Pacing items will be the reflector and the support structures. Long lead feed components are the semiconductor devices for the receive LNAs and the transmit and receive circulator switches. Communications antenna pattern analysis will be performed at commencement of this task in order to optimally design the configuration geometry and feeds.

Specifications and drawings will be made as the subsystem design proceeds. Final drawings will be completed after the qualification model has successfully passed all unit qualification tests to prove the design.

As shown in the schedule, the fabrication and assembly of unit parts for the engineering model (EM), qualification model (QM), and flight model (FM) will be done in sequence. As parts of the EM are near fabrication completion, parts of the FM will begin to be fabricated; as parts of the QM approach their assembly stage the EM model assembly will be nearing completion, and so on.

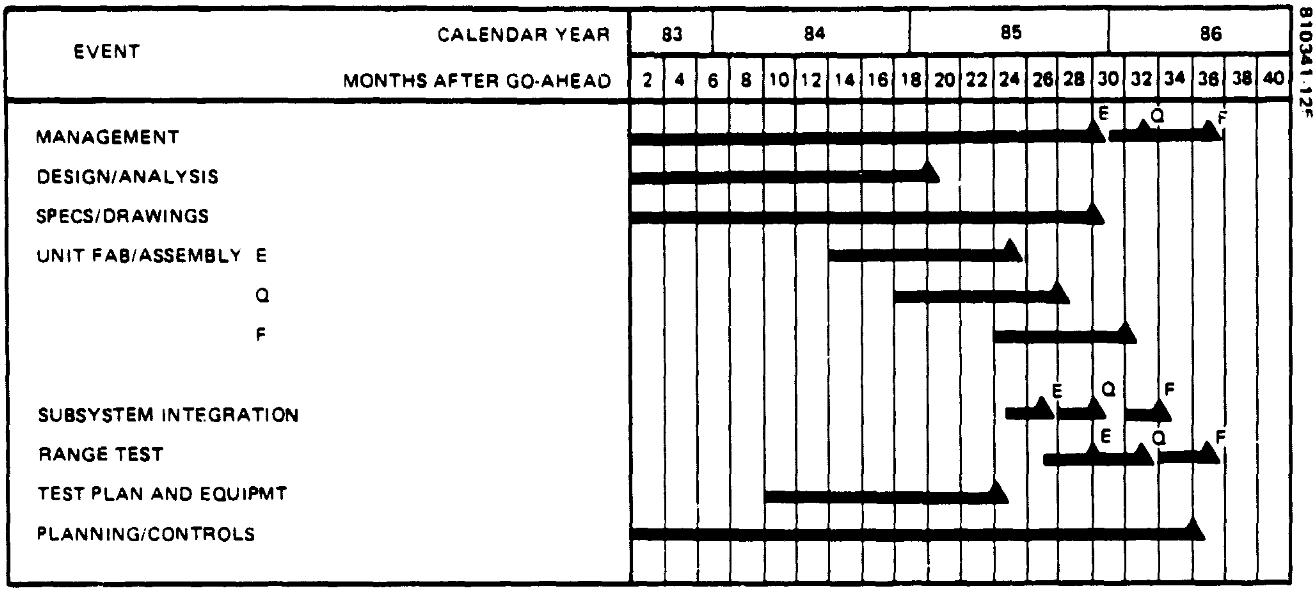

FIGURE 2-3. 30/20 GHZ ANTENNA SUBSYSTEM

Subsystem integration of the EM, QM, and FM, which consists of mounting and aligning the major component assemblies, immediately follows the completion of unit fabrication and assembly. This activity requires about 2 months for each model owing to the accuracies involved and careful handling of large assemblies. Range testing will take about 2 months for each model and follows the integration task in sequence.

In summary the driving factors/task activities of the schedule are the development (i.e., design/analysis, specifications/drawings, and fabrication) of the antenna support structures and reflectors, the phasing of subsystem range tests (EM, QM, FM) and the delivery date of the FM. The structures and main reflector are large, new and require a great amount of effort, 25 months minimum, to develop the engineering model. The engineering model consequently is a pacing subsystem among the three to be built. Proper phasing of component development with subsystem range testing from the engineering model through the FM is critical to meet its delivery due date. The antenna development plan has the benefit of experience derived from the present operational SBS and planned Intelsat VI programs.

2.3.2 30/20 GHz Baseband Processor

The development phases for the baseband processor are like those for most digital communications equipment, with some specific variations. These variations include a 12 to 15 month advanced development phase and a 3 month predevelopment phase (Figure 2-4).

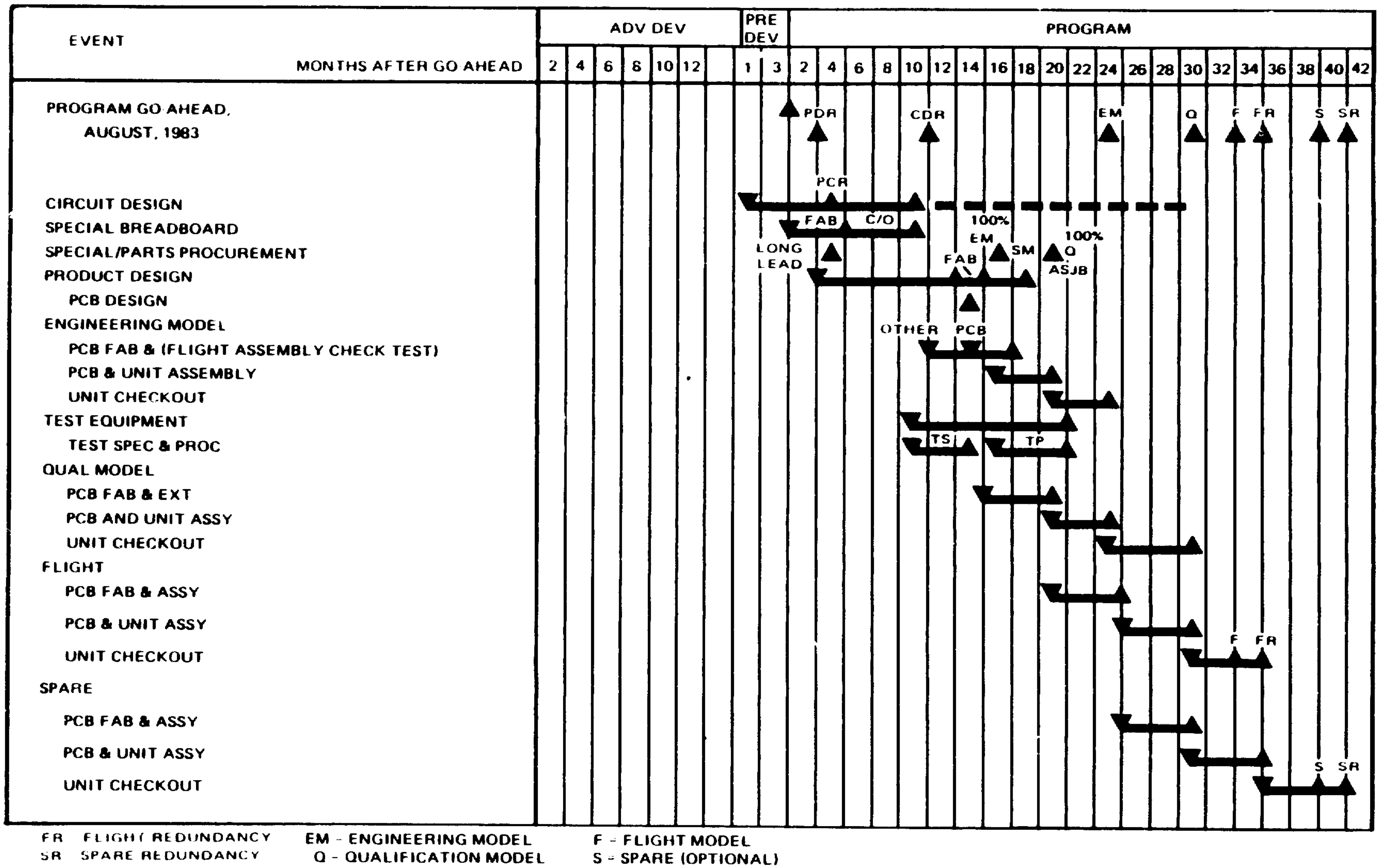

FIGURE 2-4. BASEBAND PROCESSOR

The advanced development phase is implemented to be sure that key gate array LSI devices are developed and available on time for the program, that the demodulators provide the necessary performance, and that sufficient definition of the requirements for the digital routing controller are provided. Of these efforts, the gate array development is seen as the critical path. The plan for their development is as follows: 1) definition of units which use gate arrays followed by gate array interface and architectural definition — 3 months, 2) logic design, breadboarding and checkout to verify logic (breadboard device types need not be the same as for gate array for this activity) — 2.5 months; gate array interconnect design and fabrication/assembly of proof-of-design array devices — 4 months; device evaluation — 1 month; followed by writing of unit specifications — 1-1/2 months. This 12 month effort is success oriented and may extend to 15 months. On-going IR&D, which is compatible with the needs of the advanced development phase include 1) the development of a gate-array-implemented convolutional decoder, and 2) the design and processing of a SOS-CMOS monolithic gate array chip.

The predevelopment phase exists to accommodate a baseband processor delivery schedule for the development program which is 3 months short. It is, in essence, a request for a longer development program schedule. During this period, the initial phase of circuit design occurs, bringing us to the point of initiating breadboard fabrication.

The development program proceeds with the remaining circuit development and related breadboarding. A preliminary circuit release (PCR) occurs at the end of month 3, which permits the start of product design and the ordering of long lead parts. Breadboarding is scheduled for completion at the end of month 9, at which time a final circuit release (FCR) occurs. This permits completion of product design drawings and ordering of 100 percent of parts as shown. Specifically, fabrication drawings will be complete at the end of month 12, permitting PCB fabrication to be completed 1 month later, followed by PCB FACT testing. The PCBs and units are then assembled and checked out as shown. Test equipment is designed, built and tested following FCR and in time for the engineering model checkout phase. In parallel with test equipment development, the detailed test specifications (TS) and test procedures (TP) are developed. The remaining units for qualification model, flight and spare are fabricated, assembled and checked out on schedules similar to the engineering model, with qualification testing (qualification model checkout) taking more time than the other deliverables.

2.3.3 Microwave Subsystem

The microwave subsystem program schedule is shown in Figure 2-5. The schedule shown is an overall schedule including all units of the subsystem, therefore considerable overlap of sequential activities does appear on the schedule.

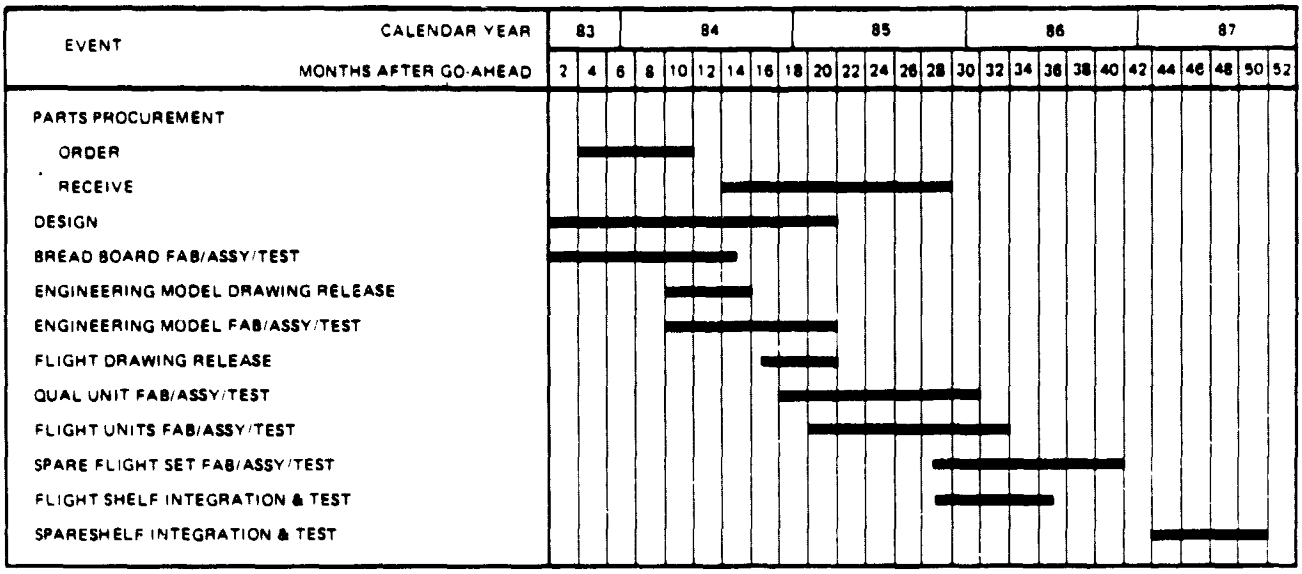

FIGURE 2-5. MICROWAVE SUBSYSTEM SUMMARY SCHEDULE

The schedule in general is not considered tight, however, certain high technology items such as the low noise amplifiers and the solid state power amplifiers are potential developmental risks.

The risk in meeting the schedule for the low noise amplifiers is in obtaining low noise devices which will meet the design requirements and qualifying these parts for flight use. The same problem exists for the solid state power amplifier where high power GaAs FET devices must be qualified for flight use. The assumption has been made that existing technology development contracts will provide devices, but that these devices must be qualified for flight use during the time span of the demonstration program contract.

In general, all flight quality parts must be available no later than 24 months after program start and most of the parts should be received by 20 months after program go-ahead in order to meet flight delivery schedules.

The flight shelf integration and test task includes not only integration and test of the microwave subsystem components but also includes integration and test of the digital units which are mounted on the flight shelf.

2.3.4 Spacecraft Bus

All spacecraft bus subsystems are based on those that have been designed, developed, and qualification tested for the LEASAT or other flight proven programs (SBS and GOES). The subsystems, for the most part, need only be assembled and flight acceptance tested. The telemetry and command subsystem format PROM changes can be implemented without affecting the unit design integrity. The substitution of the S band transponder from the

GOES program for the X band units, and removal of the encryption/ decryption equipment results in minor modification to units and does not warrant requalification.

The antenna positioning electronics (APE) is identical to that on board the operational SBS spacecraft, and the minimal interfacing with the attitude control electronics will eliminate any attitude control subsystem requalification.

The despun shelf will retain its basic design features, but will need new unit bolt holes and attachment provisions. Since the shelf has been designed to accommodate approximately 200 pounds more than the present payload weight, requalification or any special tests are not required. Also the thermal design being similar to that of the LEASAT system can be adequately tested during the shelf thermal vacuum test, and therefore requires no special thermal model or qualification tests.

The despun harness will be new and undergo the nominal harness design, fabrication, test, and bakeout operations. The planned system level tests will verify its flight worthiness.

2.3.5 System Integration and Test

The manufacturing and test sequence requires a complex system involving many contributing groups of people responsible for different tasks which must be integrated. The Hughes Space and Communications Group has been developing and improving such a production system for 16 years and is in an excellent position to meet the objectives of the program. This time period has been spent in developing systems and procedures specifically applicable to the design, development, fabrication, and test of communication spacecraft. The effort has produced one of the most complete and disciplined families of process specifications (Hughes Process Specifications — HPs) in the industry. These process specifications establish and maintain the manufacturing standards required for spacecraft subsystem fabrication.

Another result of Hughes' experience in the spacecraft field is the accumulation of test and manufacturing equipment that has been developed, improved, and utilized continually on the various programs. Tools and fixtures for thrust tube assembly, substrate fabrication, solar cell bonding, shelf layup, sun sensor alignments, digital unit production, electronic assembly, and reaction control subsystem assembly constitute a few examples of the equipment Hughes has at its disposal for the 30/20 GHz Program.

Figure 2-6 indicates the nature of the manufacturing and test sequence, beginning at the point where major components are introduced in assembly and subsystem integration. The assembly process is verified through a series of subsystem level tests. Subsystems are subsequently delivered for spacecraft integration. The assembled spacecraft is then available to begin system level testing.

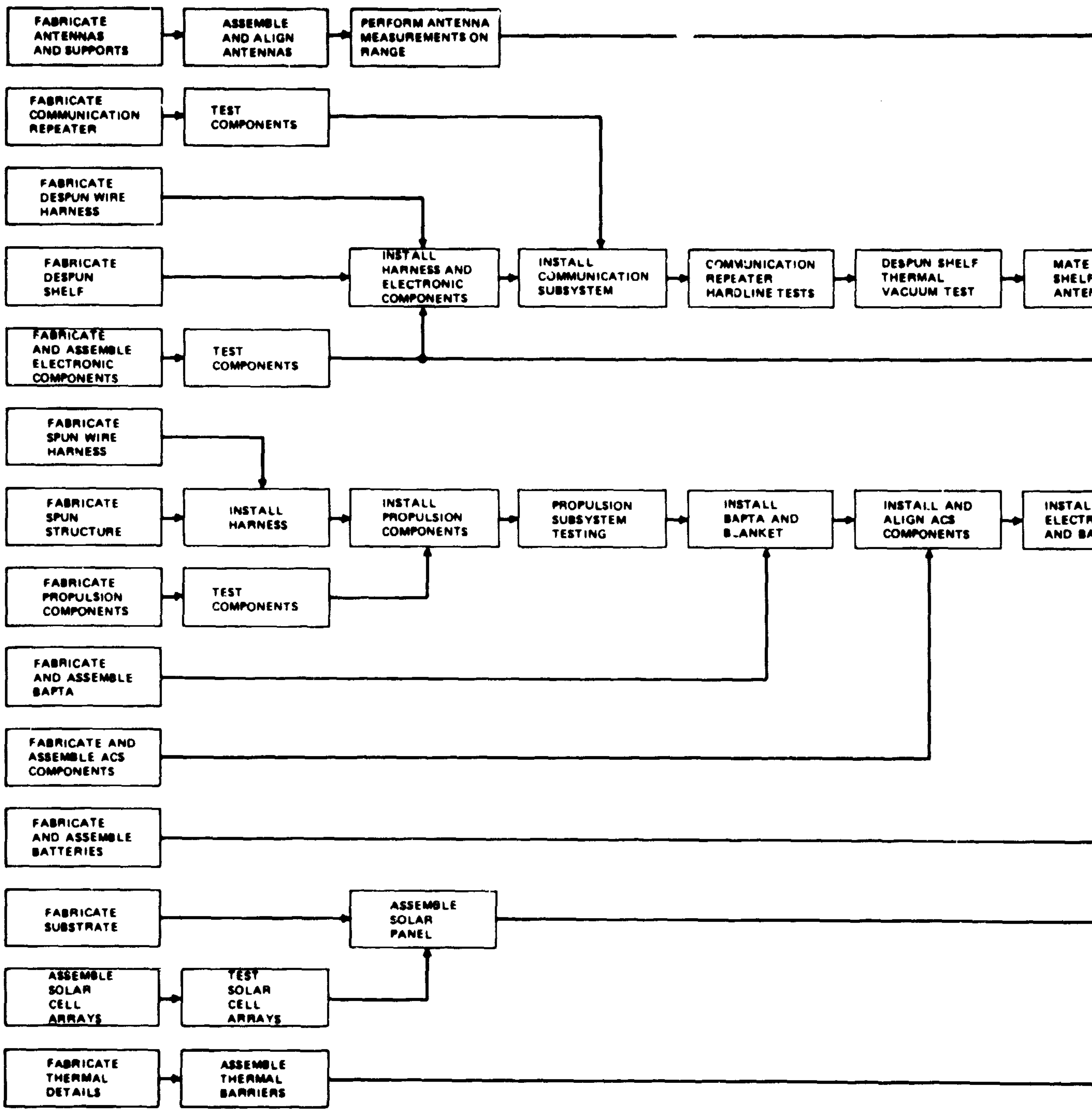

FIGURE 2-6. ASSEMBLY AND TEST SEQUENCE

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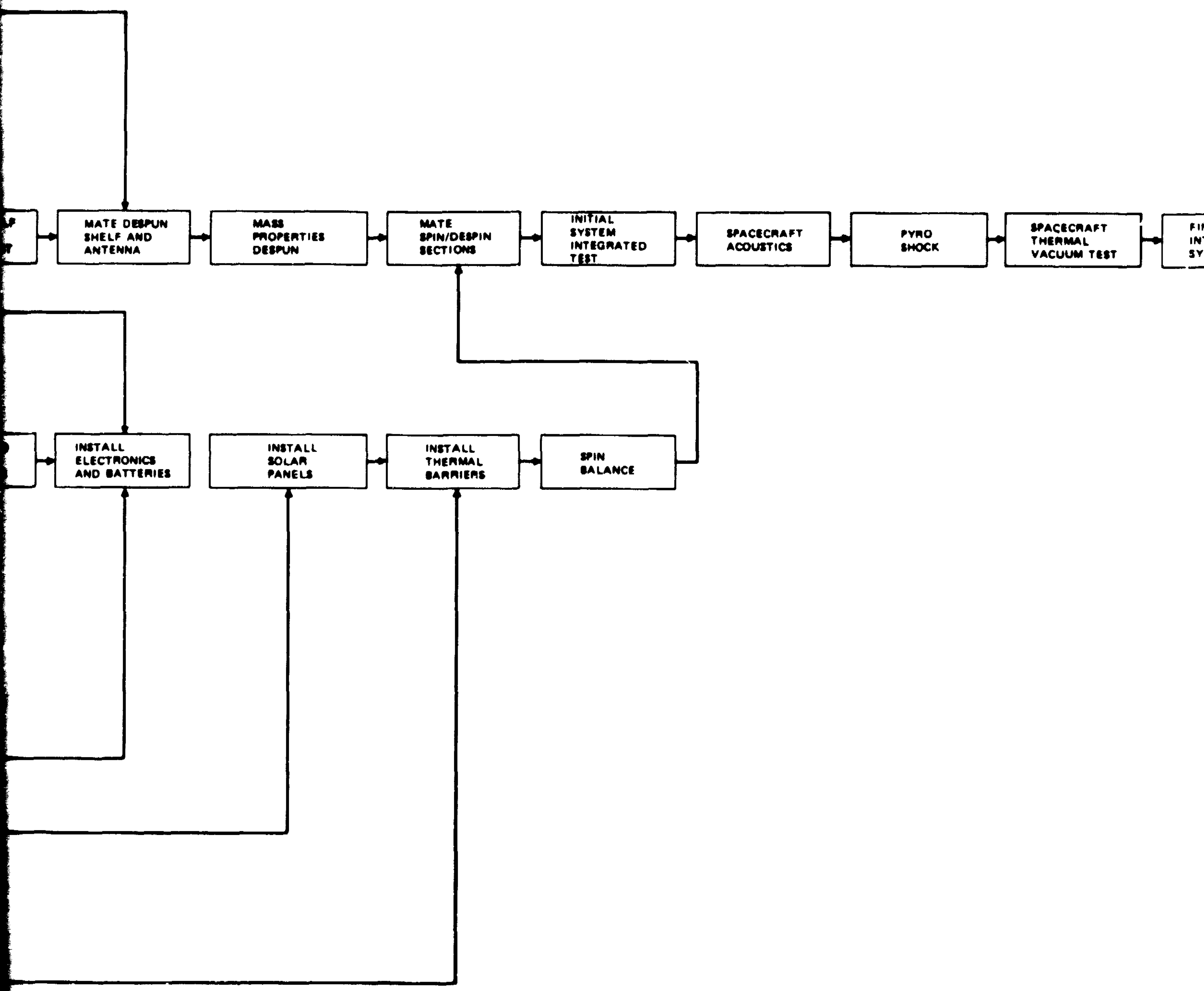

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System level testing for the program includes seven major phases as illustrated in Figure 2-7 (LEASAT example).

1) Preintegration tests, including spinning section tests, antenna tests, and despun shelf thermal-vacuum (DSTV) tests

2) Initial spacecraft integration tests (ISIT)

3) Acoustic and pyroshock

4) Spacecraft thermal-vacuum (SCTV)

5) Final integration spacecraft tests (FIST)

6) Launch operations

7) In-orbit tests (before going into operation)

Spacecraft despun units will be installed on the despun platform for extensive hardline ambient testing. In parallel, antenna development and range tests will begin, as will the buildup of the spun section. Upon completion of the ambient despun shelf tests, the shelf will be moved to the thermal-vacuum (TV) chamber, where hardline TV tests will be performed. Tests will be performed under thermal extremes of hot and cold to verify performance. Following DSTV tests, the despun shelf, spinning section, and antenna farm will be integrated for initial spacecraft integration testing (ISIT). Here, anechoic chamber tests for passive IMs will be performed. After ISIT testing, the spacecraft will go through a sequence of acoustic, pyro-shock, and spacecraft thermal-vacuum environmental tests to ensure performance margin during and after exposure to these environments. Final integration systems tests (FIST) will verify spacecraft performance before the spacecraft is shipped to the Eastern Test Range for launch.

2.3.6 Terrestrial Segment

Most of the terrestrial segment equipment can be developed comfortably within the 30/20 GHz program schedule and need not begin immediately at program go-ahead (see Figure 2-8). The exceptions are the following hardware items that require special technology development to begin at the start of the program.

1) Antenna Feed. Hughes Fullerton has built a 40/20 GHz feed which would be scaled down to meet NASA's 30/20 GHz requirement. In this connection the major concern is the orthomode transducer which will require special attention to the receive port impedance match, considering the relatively wide bandwidth involved. To be conservative, a development phase is included in the procurement of the feed whereby this concern may be realistically dealt with.

2) <u>High Power Amplifier</u>. The 125 watt TWT required for the trunking sites will be developed from an existing design, Hughes Model 914H. Based on this design plus preprogram technology development effort, a new TWT that satisfies 30/20 GHz program specifications will be produced within the 18 month schedule.

The 20 watt TWT required for the CPS stations will be developed from an existing 30 watt 28 GHz model, Hughes 950H. The redesign necessary for the higher frequency operation and new tooling will be available within the 18 month time period.

3) <u>Upconverter/Downconverter</u>. Hughes is one of the very few aerospace companies that have developed and fabricated these units in the frequency range of interest. Up and downconverters built by the Hughes Ground Systems Group are delivered and operating in the 20 to 40 GHz range. These units could be adapted to meet the 30/20 GHz requirement. Some adaptation development effort nonetheless will be allocated to resolve any unexpected isolation, intermod, spur problems, or other problems presented in the requirements of the unit themselves, i.e., filters, amplifiers, isolators, mixers, attenuators, etc.

The standard or off-the-shelf items can all be procured in a reasonable period of time. All earth station equipment including the special microwave interconnecting hardware for diversity will be acceptance tested at the factory and shipped to operational sites for integration and field acceptance testing. Special emphasis will be given to the interfaces to ensure full compatibility with the earth station data processing equipment. Specific equipment will be made available to the spacecraft payload subsystem and system level testing to ensure satisfactory end-to-end performance.

The software will be based on that available from the LEASAT system and supplemented to fulfill 30/20 GHz communication and experiment needs. A large part of the software will be developed early in the program to support spacecraft system level testing. The same software will be used for on-orbit operations thereby minimizing costs.

The RF and baseboard experience gained from the SBS and TDRS programs plus the system architectural, demand assignment, and mission operations expertise derived from the Palapa, GMS, and LEASAT programs will be applied to the 30/20 GHz program.

2.4 WORK BREAKDOWN STRUCTURE

The 30/20 GHz Program work breakdown structure (WBS) to level III is shown on Figure 2-9. The first three items on level II relate to the overall program direction, control, performance, and system quality: program management, systems engineering, and product effectiveness. Program management and product effectiveness include not only the typical tasks as listed on Tables 2-2 and 2-3, but an additional program level technology consultant task under program management, and system safety (STS), radiation design, new technology, and enhanced subcontract monitoring under product effectiveness.

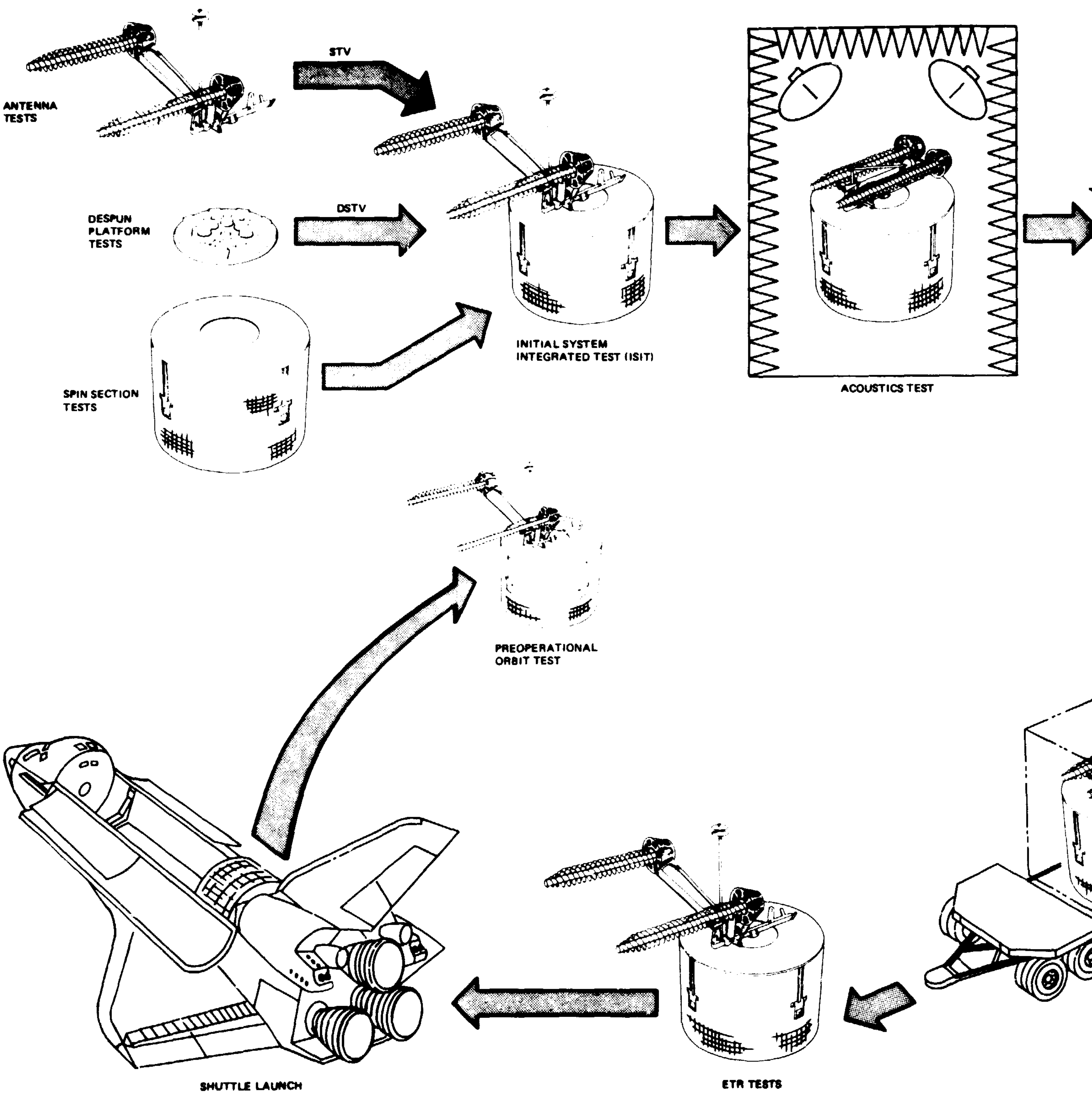

FIGURE 2-7. SYSTEM TEST PROGRAM VALIDATES REQUIRED SYSTEM PERFORMANCE.

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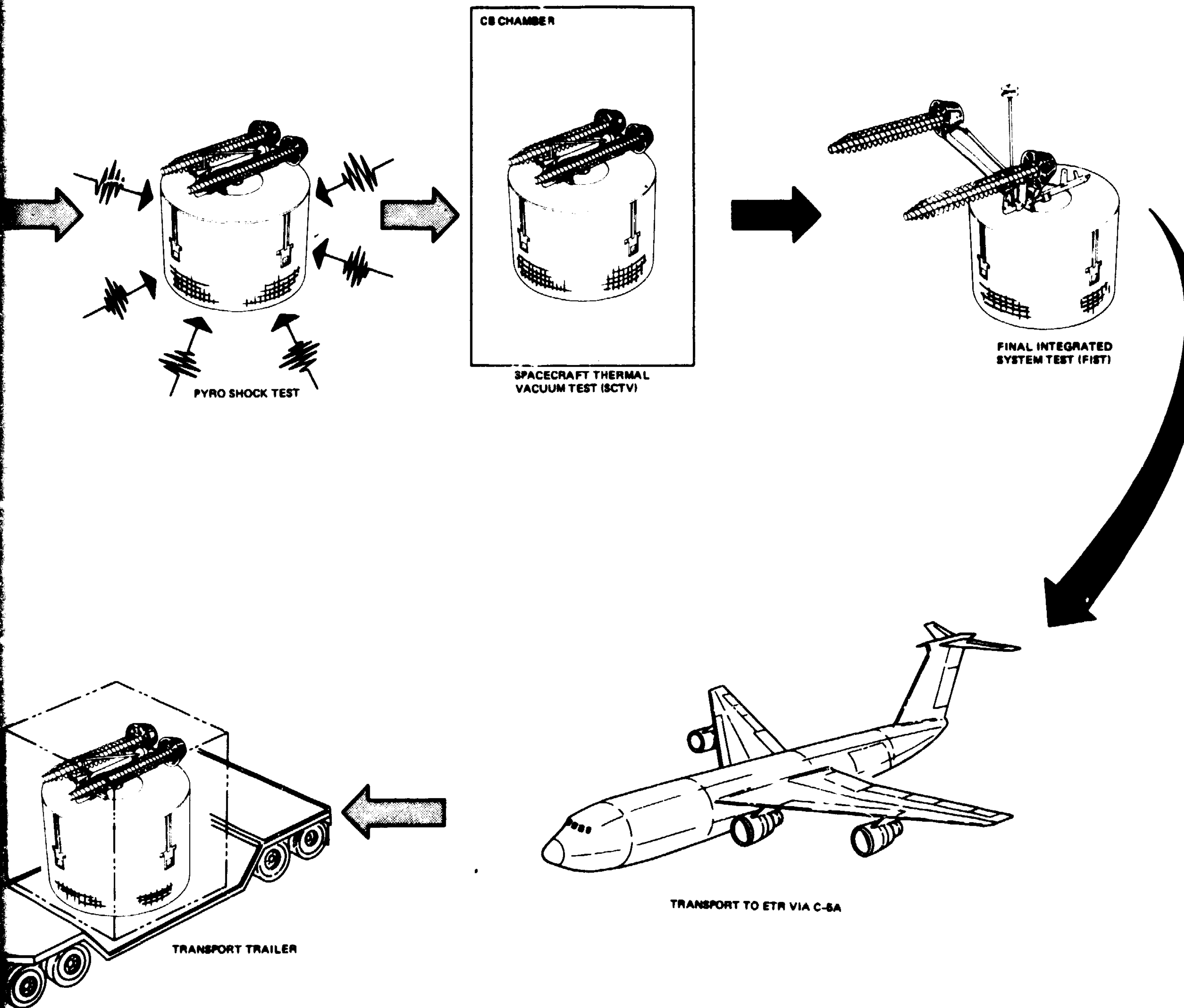

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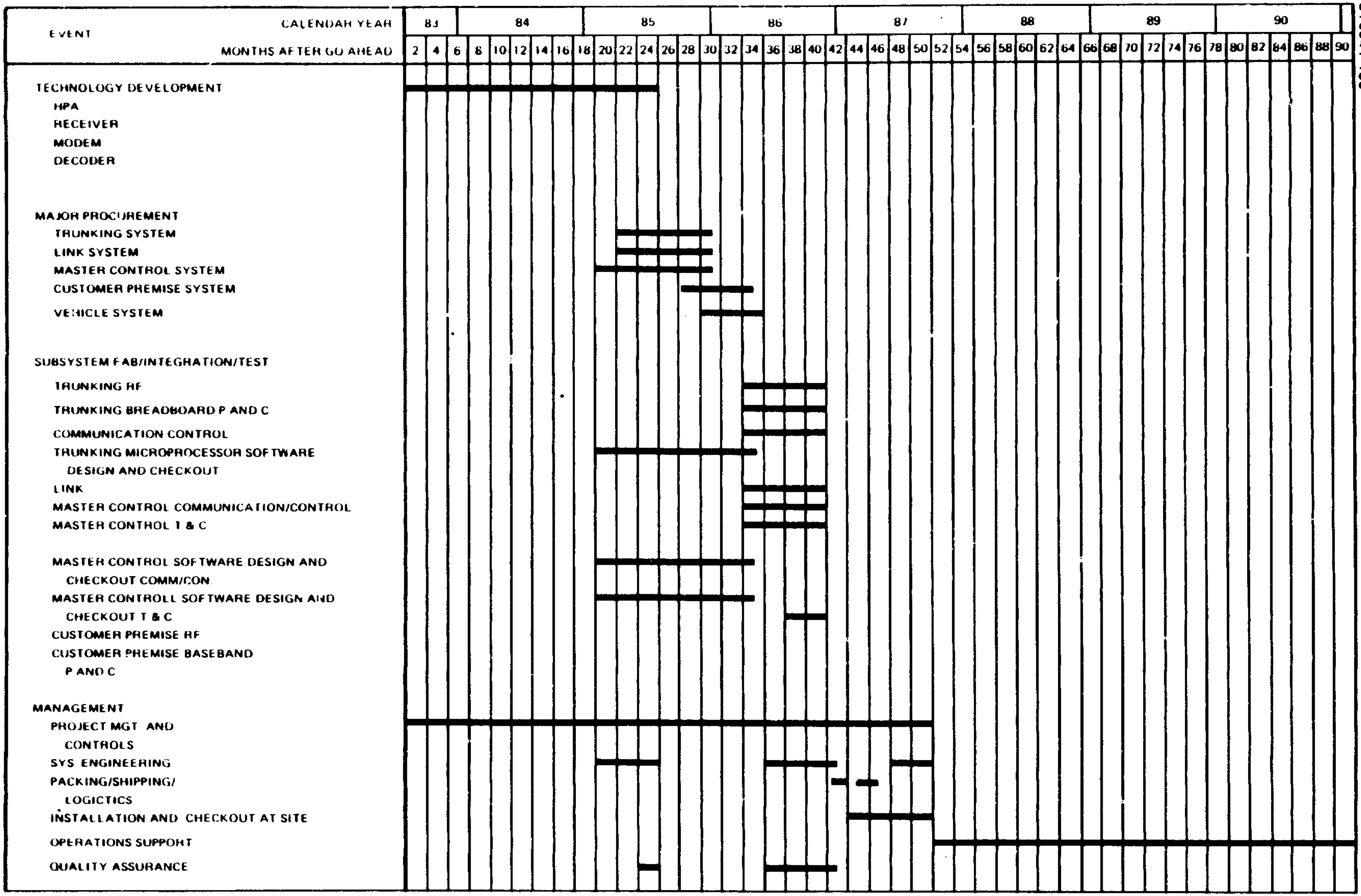

FIGURE 2-8. TERRESTRIAL SEGMENT PHASING SCHEDULE

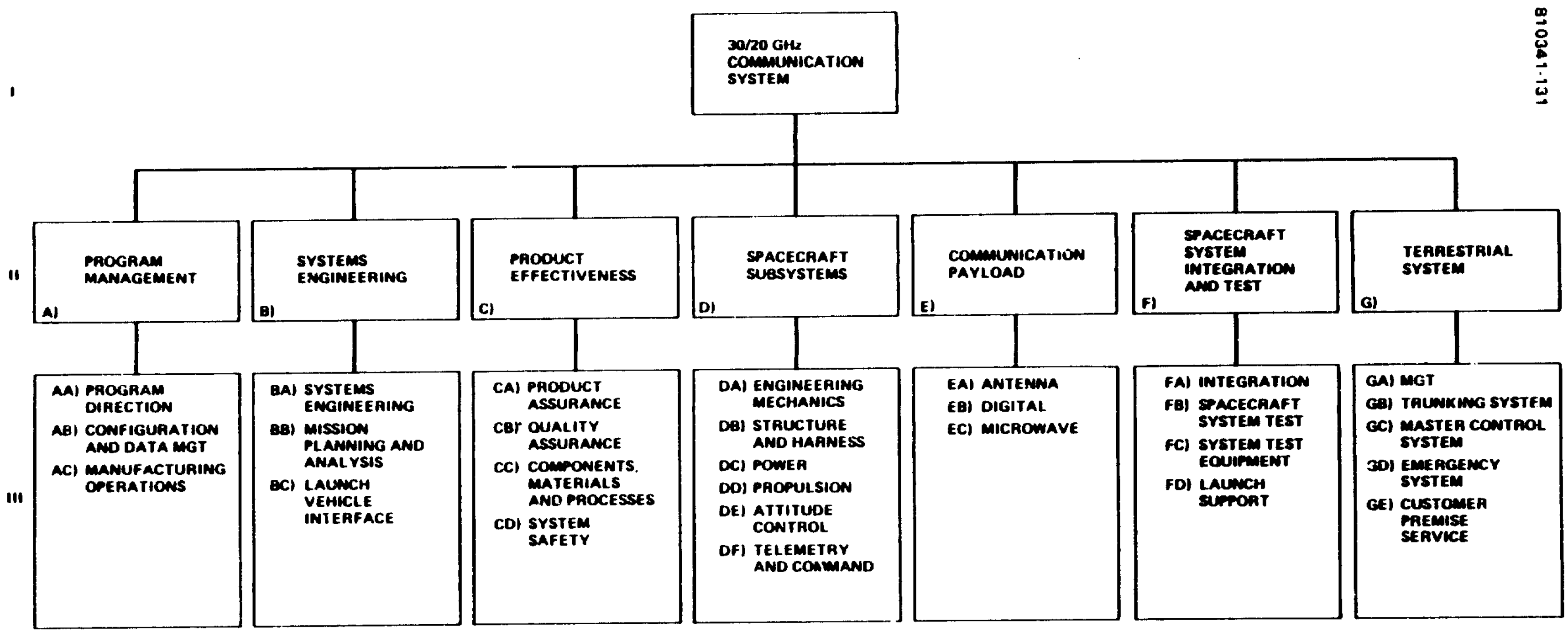

FIGURE 2-9. 30/20 GHZ WORK BREAKDOWN STRUCTURE

TABLE 2-2. PROGRAM MANAGEMENT

• Managers
• Technology consultants
• Cost/schedule control
• Configuration management
• Data management
• Parts management
• Subcontracts
• Manufacturing

TABLE 2-3. PRODUCT EFFECTIVENESS TASKS

• PA* and reliability management
• Reliability analysis and engineering
• Quality assurance management
• Quality control
• Components and materials
• Component radiation characterization
• System safety

*Product Assurance

The system engineering tasks include the flight and ground system elements encompassing the spacecraft bus, payload, Shuttle interface, ground terminals, master control station, and total system architecture and design. The tasks have been selected to ensure that the system is approached from the "top-down" to generate a complete specification and a system that satisfies program key objectives. Table 2-4 lists the system engineering work breakdown structure (WBS).

The remaining four level II items; spacecraft subsystems, communication payload, spacecraft system integration, and test and terrestrial system are subdivided in a conventional manner. The detailed level III, and below, WBS is presented in the following section.

2.5 ROM COST DATA

The 30/20 GHz program ROM costs (1981 $M) based on the previously presented development plan are summarized in Table 2-5. These costs are shown spread over the fiscal years and include G and A and fee. The subsystems cost for an optional spacecraft are included, but the system integration and tests costs are not included. Shuttle launch costs are not shown.

TABLE 2-4. SYSTEM ENGINEERING WBS

- Managers
- Communications system engineers
  - Manager
  - RF/link
  - Digital
  - Architecture/software
  - Antenna
  - Communications operations
- Spacecraft bus engineers
  - Manager
  - Telemetry
  - Controls
  - Power
  - Harness
  - EMC
- System engineers
  - System specification
  - Integrated test plan
  - Launch vehicle integration
  - Mission operations
  - Experiment operations
  - Orbital dynamics
  - Other
- Mission support

The program management tasks, listed in Table 2-6, represent those efforts needed to direct and control the overall program. The cost for this task is 8 percent of the total subsystem costs based on recent comparable programs.

Table 2-7 lists the system engineering tasks and associated man-months for each. The communications system engineering tasks encompass both the spacecraft payload and ground system. The objective is to apply system engineering to the total communications subsystem in an end-to-end manner. The system engineering costs are approximately 6 percent of the total subsystem costs which is consistent with this cost on comparable programs.

TABLE 2-5. COST SUMMARY, 1981 $M

	FY83	FY84	FY85	FY86	FY87	FY88	FY89	Total
Program management (8%)	0.5	3	3	3	3	–	–	12
Systems engineering	0.4	2.2	2.2	2.2	2.2	0.3	0.3	9.8
Product effectiveness (10%)	0.6	4.3	4	4.4	1.3	–	–	14.6
System integration and test*	–	–	2	8	5.7	–	–	15.7
Flight systems	6	42	37	25.7	2.4	–	–	113.1
Ground terminals	0.1	0.9	1	5.5	3.2	–	–	10.7
Master control station	–	–	0.4	5.1	1.6	–	–	7.1
Operations, maintenance and support	–	–	–	–	–	0.9	0.9	1.8
Subtotal	7.6	57.9	55.1	53.9	19.4	1.3	1.3	185
G&A (12%)	0.9	7	6.6	6.5	2.3	0.2	0.2	22.2
Fee (15%)	1.3	9.7	9.3	9.1	3.3	0.2	0.2	31.1
Total	9.8	69.6	66	69.5	25	1.7	1.7	238.3

TABLE 2-6. PROGRAM MANAGEMENT TASKS

- Managers
- Technology consultants
- Cost/schedule control
- Configuration management
- Data management
- Parts management
- Subcontracts
- Manufacturing

Based on recent programs such as Pioneer Venus, SBS, and other commercial programs, Program Management is limited to approximately 8% of the subsystem costs.

The product effectiveness tasks listed in Table 2-8 are estimated to cost 10 percent of the total subsystem costs. Previous programs have only cost 6 percent, but the additional costs associated with Shuttle safety, electronic radiation hardening, new technology, and system complexity result in an additional 4 percent for a total of 10 percent.

The subsystem referred to above includes system integration and test, flight system, ground terminals, and master control station. The system integration and test includes spacecraft integration and test, launch operation, and $1.1M for ground segment preflight simulations and tests. The spacecraft integration and test, and launch operations cost estimates are derived for the LEASAT costs. The ground segment costs are based on GMS, Palapa, LEASAT, and SBS experience.

*Integration and testing of major systems including master control station simulations, GSFC simulations and launch base support = $1.1M.

TABLE 2-7. SYSTEM ENGINEERING TASKS

Tasks	Man-Months
• Managers [(1 man x 50 ms) + (0.5 x 50)]	75
• Communications system engineers	
• Manager (1 x 50)	50
• RF/link (1 x 50)	50
• Digital (2 x 50)	100
• Architecture/software (3 x 50)	150
• Antenna (1 x 50)	50
• Communications operations (1 x 50)	50
	450
• Spacecraft bus engineers	
• Manager (1 x 50)	50
• Telemetry/command (1 x 50)	50
• Controls (1 x 50)	50
• Power (1 x 50)	50
• Harness (0.5 x 50)	25
• EMC (0.5 x 50)	25
	250
• System engineers	
• System specification (0.5 x 50)	25
• Integrated test plan (0.5 x 50)	25
• Launch vehicle integration (0.5 x 50)	25
• Mission operations (1 x 50)	50
• Experiment operations (1 x 50)	50
• Orbital dynamics (2 x 50)	100
• Other (2 x 50)	100
	375
• Mission support (6 x 24)	144
Total	1294

∴ 1294 x $8.2K/MMO = $10.6M

The flight systems costs include the communications payload and spacecraft bus (including perigee kick motor)* costs. Tables 2-9, 2-10, 2-11, and 2-12 give detailed subsystem costs plus appropriate contingencies for these flight system elements. These tables also list costs for the associated engineering, qualification, and flight models, and spare and test equipment. The digital subsystem costs do not include a preprogram go-ahead LSI development cost of approximately \$2.5M.

Table 2-13 is a flight system cost summary that includes system assembly, integration, and test, and the related product assurance costs. The additional costs for the optional second flight are noted.

TABLE 2-8. PRODUCT EFFECTIVENESS TASKS

- PA and reliability management
- Reliability analysis and engineering
- Quality assurance management
- Quality control
- Components and materials
- Component radiation characterization
- System safety

Based on recent programs such as GOES, GMS, and Pioneer Venus, Product Assurance is limited to approximately 6% of the subsystem costs. Since future requirements will place emphasis on the following items, a limit of 10% is appropriate:

Safety	≈ 1%
Radiation	≈ 1%
New technology	≈ 1%
System complexity	≈ 1%

∴ 6% + 4% = 10%

TABLE 2-9. SPACECRAFT BUS COSTS*, 1981 \$M

Task	Engineering Model	Test Equipment	Qual Model	Flight Model	Spare	Total
Management	–	–	0.061	0.382	0.382	0.825
Engineering	–	–	2.617	3.587	0.751	6.955
Structure	–	–	1.383	1.383	1.387	4.153
Power	–	–	–	4.542	4.542	9.084
Propulsion	–	–	–	4.312	4.312	8.624
Attitude control	–	–	–	1.554	1.554	3.108
Telemetry and Command	–	–	–	2.361	2.361	4.722
Totals	–	–	4.061	18.121	15.281	37.4

*Includes 5% contingency.

*Integrated PKM replaces SSUS-A upper stage.

TABLE 2-10. ANTENNA COSTS*, 1981 $M

Task	Engineering Model	Test Equipment	Qual Model	Flight Model	Spare	Total
Management	0.665	0.180	0.336	0.269	QM	1.450
Engineering	0.919	1.560	0.464	0.372	QM	3.315
Reflector	1.908	0.216	1.008	0.720	QM	3.852
Subreflector	0.984	0.060	0.439	0.276	QM	1.759
Frequency select surface	0.792	0.012	0.389	0.192	QM	1.385
20 GHz feed	0.834	0.120	0.288	0.174	QM	1.416
30 GHz feed	0.828	–	0.317	0.216	QM	1.361
30 GHz track circuit	0.624	–	0.331	0.192	QM	1.147
T&C Omni antenna	–	–	0.022	0.018	QM	0.040
Beacon antenna	–	–	0.209	0.174	QM	0.383
Support structures	1.218	0.084	0.389	0.324	QM	2.015
Thermal protection	0.144	–	0.086	0.072	QM	0.302
Totals	8.916	2.232	4.278	2.999	–	18.4

*Includes 20% contingency

TABLE 2-11. MICROWAVE COSTS*, 1981 $M

Task	Engineering Model	Test Equipment	Qual Model	Flight Model	Spare	Total
Management	1.038	0.043	0.348	0.902	0.896	3.227
Engineering	6.306	0.683	0.124	0.434	0.434	7.981
Frequency source	0.220	–	0.140	0.282	0.282	0.929
Monopulse electronics	0.243	–	0.139	0.156	0.156	0.694
TWT power supply	0.228	–	0.151	0.760	0.633	1.77
Variable power divider	0.312	–	0.127	0.104	0.104	0.647
Low noise amplifiers	0.119	–	0.042	0.556	0.556	1.273
Receivers	0.603	–	0.343	1.857	1.857	4.660
IF switch matrix	0.438	–	0.288	0.258	0.258	1.242
Upconverters	0.330	–	0.195	1.043	1.043	2.61
TWT	0.628	–	0.154	0.745	0.621	2.148
Solid state Pwr. amplifiers	1.025	–	1,407	2.708	2.708	7.845
Switch monitors, and filters	0.930	–	0.310	0.992	0.992	3.224
Totals	12.42	0.726	3.767	10.797	10.54	38.2

*Includes 20%, contingency.

TABLE 2-12. DIGITAL COSTS*, 1981 $M

Task	Engineering Model	Test Equipment	Qual Model	Flight Model	Spare	Total
Management	0.154	0.052	0.103	0.103	0.103	0.515
Engineering	6.617	1.310	0.171	0.171	0.171	8.440
Data Processor No. 1	0.152	0.001	0.044	0.033	0.028	0.258
Data Processor No. 2	0.022	0.001	0.016	0.011	0.041	0.091
Decoder	0.036	0.024	0.033	0.056	0.031	0.180
Store and forward	0.915	0.056	0.747	1.044	0.871	3.633
Encoder and output mux	0.007	0.001	0.006	0.003	0.004	0.021
Digital routing cont.	0.138	0.010	0.087	0.140	0.130	0.505
Scan beam cont.	0.075	0.007	0.047	0.205	0.185	0.519
IF downconverter	0.056	0.004	0.036	0.089	0.087	0.272
IF switch cont.	0.066	0.001	0.042	0.072	0.067	0.241
Inter. unit	0.105	0.006	0.080	0.098	0.098	0.387
32 Mbps demod.	0.259	0.006	0.147	0.609	0.775	1.796
IF routing switch	0.034	0.002	0.024	0.043	0.043	0.146
128 Mbps demodulator	0.308	0.007	0.151	0.382	0.470	1.318
256 Mbps mod. and upcn.	0.055	0.004	0.037	0.072	0.068	0.236
Power supply	0.074	0.010	0.054	0.083	0.079	0.3
Total	9.073	1.502	1.825	3.214	3.251	18.9

*Includes 20% contingency.

TABLE 2-13. FLIGHT SYSTEM COSTS, 1981 $M

Item	Engineering Model	Test Equipment	Qual Model	Flight Model	Spare	Total
Communications payload	30.4	4.5	9.9	17	13.8	75.6
Spacecraft bus	–	–	4.1	18.1	15.3	37.4
Assembly, integration, and test	–	–	–	14.6	7.2*	21.8*
Product assurance	3.7	0.5	1.5	5.2	3.9*	14.8*
Total	34.1	5	15.5	54.9	40.2*	149.7*

*Option included.

TABLE 2-14. GROUND TERMINAL COSTS*, 1981 $M

Terminals	Development	First Unit	Total
Trunking			
Management	0.332	0.332	0.664
Systems engineering	0.457	0.154	0.611
RF subsystem	1.893	0.919	2.812
Baseband processor and control	0.080	2.928	3.008
Link subsystem	–	0.539	0.539
Logistics/travel	–	0.040	0.040
Integration and test	–	0.053	0.053
Product assurance	–	0.013	0.013
Spares	–	0.367	0.367
Total	2.762	5.345	8.107
CPS			
Management	0.166	0.166	0.332
Systems engineering	0.204	0.077	0.281
RF subsystem	–	0.447	0.447
Baseband processor and control	–	0.952	0.952
Logistics/travel	–	0.040	0.040
Vehicle	0.052	0.112	0.164
Integration and test	–	0.027	0.027
Product assurance	–	0.013	0.013
Spares	–	0.367	0.367
Total	0.422	2.201	2.623

*Includes 10% contingency.

TABLE 2-15. CENTRAL CONTROL STATION *, 1981 $M

Management	0.700
Systems engineering	0.638
Communication control subsystem	1.397
Interface units	0.485
Software	2.110
TT&C subsystem	0.698
Integration and test	0.053
Product assurance	0.013
Test equipment	0.614
Spares	0.367
Logistics/travel	0.040
Total	7.1
Option – site preparation and construction	0.3M

*Includes 15% contingency.

Table 2-14 lists the cost breakdown for the trunking and CPS terminals. Shown are the development and first unit costs including a 10 percent contingency. The special TWTA development costs are contained in the trunking terminal RF subsystem line item.

Table 2-15 gives the cost breakdown for the central control station. The cost of all software necessary to support the mission operations, communications operations, and basic experiment operations has been included. Optional site preparation and construction would cost $0.3M. All values include 15 percent contingency.

The launch, transfer orbit, orbit and maintenance operations plus 10 percent contingency are given in Table 2-16. These costs relate to ground segment tasks only [not flight system preparation at Eastern Test Range (ETR)].

Tables 2-17 and 2-18 give recurring costs for a large buy (20) of trunking and CPS terminals. Three and five meter diameter antenna dish configurations are presented. The items not included in these costs are noted.

TABLE 2-16. OPERATIONS, MAINTENANCE, AND SUPPORT*, 1981 $M

Operations	Costs	
Launch		0.132
Simulations	0.026	
Operations	0.106	
Transfer orbit		0.536
Simulations	0.322	
Operations	0.215	
Orbit		1.072
Simulations	0.429	
Housekeeping	0.215	
Experiment	0.429	
Maintenance		1.072
Master control station	0.429	
Trunking terminals	0.429	
CPS terminals	0.215	
Total		2.813

*Includes 10% contingency.

TABLE 2-17. C[illegible]S RECURRING COSTS*, 1981 $M
(QUANTITY 20)

	3M	5M
Antenna	0.003	0.027
Feed	0.037	
High power amplifier (20 W)	0.030	
Low noise amplifier	0.011	
Up/downconverter	0.017	
Frequency synthesizer	0.017	
Frequency standard	0.017	
MUX/DEMUX (32 Mbps to 128 Mbps)	0.044	0.089
Modem	0.400	
Test loop translator	0.022	
D/L processor	0.022	
Microprocessor	0.011	
Total	0.630	0.699

*Does not include management, engineering, product effectiveness, vehicle, contingency G&A, or fee.

TABLE 2-18. TRUNKING RECURRING COSTS*, 1981 $M
(QUANTITY 20)

Antenna (5M)	0.055
Feed	0.074
High power amplifier (200 W)	0.324
Low noise amplifier	0.022
Up/downconverter	0.033
Frequency synthesizer	0.017
Frequency standard	0.017
MUX/DEMUX	0.157
Modem	0.800
Test loop translator	0.0[illegible]
D/L processor	0.022
Microprocessor	0.011
U/L processor	0.022
Baseband processor	0.022
Link subsystem	0.490
Total	2.134

*Does not include management, engineering, product effectiveness, G&A, or fee.